Reese Creek Flume Calibration Study – Phase 1: Literature Review

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1 INTRODUCTION

Reese Creek is located along the northern boundary of Yellowstone National Park and flows into the Yellowstone River downstream of Gardiner, Montana. The United States is party to a complex water rights agreement involving the waters of Reese Creek. An agreement was signed in July 1990 distributing the waters of Reese Creek among four users, including the United States. As part of this agreement, the National Park Service (NPS) is obligated to construct and install water measurement structures at appropriate points along Reese Creek.

One of these structures is a Parshall Flume with a five-foot throat width. NPS hydrologist discovered that the rated discharge for given gage heights within the flume did not agree with the manual discharge measurements taken over a range of flows. After a field visit involving Colorado State University, Engineering Research Center staff, it was determined that the flow entering the flume was in a supercritical state which the flume was not designed to measure.

Colorado State University has been tasked to investigate the possibility of determining a calibration equation for the Parshall flume installed and discussed above as a flow measurement device in Reese Creek. As Parshall flumes are designed to measure subcritical flow, utilizing the published rating equation will provide inaccurate estimates of in-channel flow. One option for solving the problems associated with flow measurement in Reese Creek would be to generate a set of empirical rating equations for the flumes currently installed in Reese Creek. A three (3) phase research plan has been formulated to investigate this option. Phase 1 will provide a review of the available literature. Phase 2 consists of conducting tests at a small scale to examine the feasibility of the approach and Phase 3 will encompass full scale testing should the results of Phase 2 warrant further testing. Please see the proposal for full details pertaining to each phase. This report documents the finding from Phase 1 and provides field characteristics from the Reese Creek flumes necessary for the initiation of Phase 2.

2 LITERATURE REVIEW

2.1 INTRODUCTION

An examination of all Parshall flume literature was the starting point for the discovery of information pertaining to existing equations for measuring flow during supercritical conditions. In an effort to discover additional information regarding the measurement of flow during supercritical conditions, the literature review was expanded to include Cutthroat flumes and any other open channel flow measuring flume utilized during supercritical conditions. Cutthroat flumes were included due to the similarity of the two types of measuring flumes.

Cutthroat and Parshall Flumes utilize a constricting entrance to force a subcritical entrance flow through a critical state. When critical flow occurs within the constriction, the stage-discharge relationship does not depend on downstream conditions and can be determined from a single upstream depth measurement. For accurate flow measurement, Parshall and Cutthroat flumes, as with all critical-depth flumes, are dependent upon critical flow occurring within the constricting portion of the flume.

A site visit concluded that the flow entering the flumes currently installed at Reese Creek was in a supercritical regime. Consequently, the constricting entrances of the flumes are unable to force the entering flow into a critical state within the constricting entrance. Thus, utilizing standard stage-discharge relationships would yield inaccurate flow estimates. In an effort to empirically determine calibration equations for the critical-depth flumes currently installed at Reese Creek, a literature review was conducted.

2.2 BACKGROUND INFORMATION

Various critical-depth flumes have been developed and implemented in the measurement of open-channel flow. Even though both Parshall and Cutthroat flumes are critical-depth measurement flumes, geometric and operating differences between these flumes makes background information upon both flumes essential.

2.2.1 PARSHALL FLUMES

During the early 20th Century, Ralph Parshall conducted tests upon his improvement to the Venturi Flume, later to be named in his honor as the Parshall Flume. The original Venturi Flume required the measurement of two water depths, which were then averaged and referenced to a discharge diagram to determine flow rate. Parshall's improvement to the Venturi Flume allows for discharge to be determined by a single up-stream measurement under free flow conditions. The Parshall flume operates similar to all other critical-depth flumes. The converging entrance forces the subcritical entrance flow through critical depth. Thus, the constricted entrance produces a differential head that can be related to discharge though stage-discharge relationships. Next, flow progresses through the constant width, declined throated section. For free flow conditions, the momentum of the water allows the flow to be carried from the throated section over the inclined floor of the diverging section and then exits the flume. Figure 2.1 depicts a cross-sectional view and plan view of a Parshall flume.

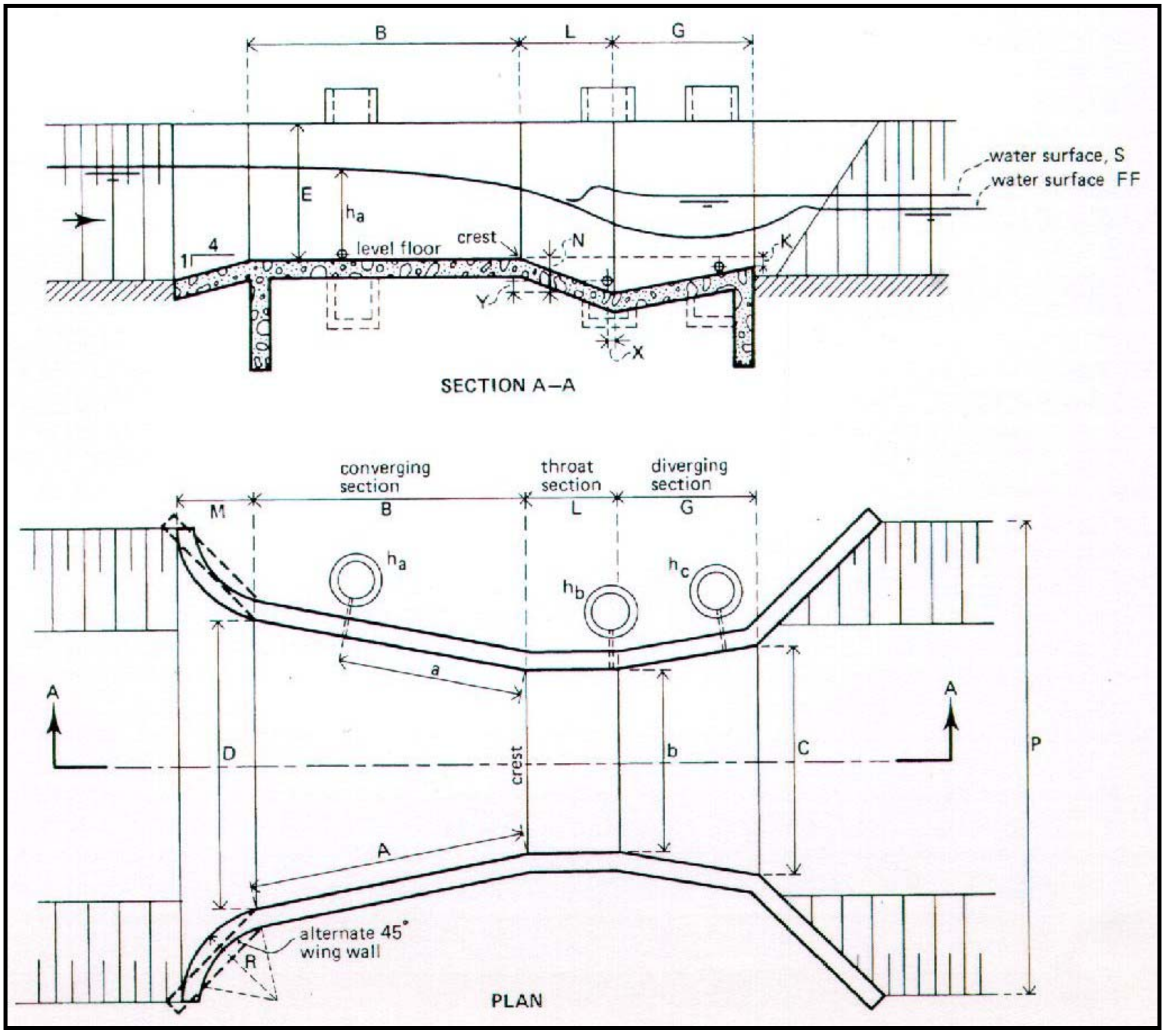


Figure 2.1 – Dimensions of Parshall flume (Bos, et al. 1989)

As previously addressed, for free flow conditions the stage-discharge relationship can be determined from a single upstream depth measurement. For submerged and very small Parshall flumes, two water heights are required to obtain discharge. These exceptions will not be addressed. The fundamental law governing free-flow discharge through the Parshall flume can be derived as:

$$Q = JH_a^{\ n}$$ **Equation 2.1**

where: Q=Discharge, ft^3/s;
J=Coefficient dependent upon flume size;
H_a=Upstream head measured upstream of the crest at a distance equal to two-thirds the length of the converging section, ft; and
n=Exponent of the head, H_a (Ranges from 1.522-1.60 for Parshall Flumes).

Parshall's original equation governing free-flow discharge through flumes was derived for a throat width (W) ranging from 1 to 8 feet. Free-flow discharge through a Parshall Flume with widths ranging from 1 to 8 can be computed from the following equation:

$$Q = 4WH_a^{1.522W^{0.026}} \quad \textbf{Equation 2.2}$$

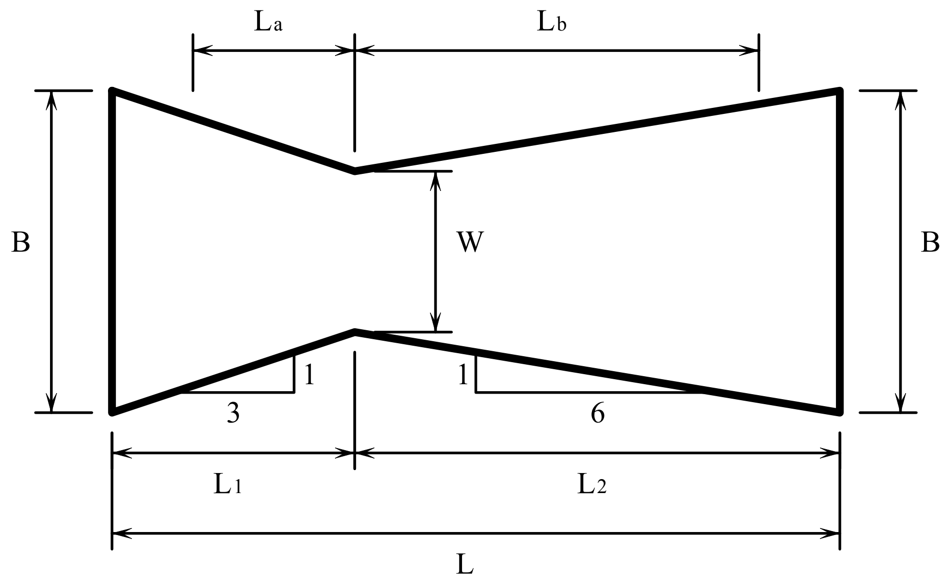
where: Q=Discharge, ft^3/s;
W=Width of throat, ft; and
H_a=Up-Stream head measured up-stream of the crest at a distance equal to two-thirds the length of the converging section, ft.

The Parshall flume provides many advantages over other conventional open-channel flow measuring devices. Parshall flumes can operate with relatively small head loss and the converging entrance throat eliminates sediment deposition within or upstream of the structure. Parshall flumes can measure discharge with no submergence, moderate submergence and considerable submergence of the downstream structure. Due to the flow acceleration through the converging throat, the Parshall flume has a low sensitivity to the approach velocity. However, the approaching flow should be well distributed across the entire channel and free of turbulence, eddies and waves.

Since implementation in the agricultural industry, vast experimental testing has been conducted upon Parshall's original design. Some of these investigations have included correction factors of uneven settlement of flumes, correction factors for small Parshall flumes, and scaling effects of Parhsall flumes. An examination of the Parshall flume literature did not produce any studies related to the development of a rating equation for supercritical flow conditions.

2.2.2 CUTTHROAT FLUMES

Cutthroat flumes, like Parshall flumes, are a critical-depth, open channel flow measurement flume. Cutthroat flumes also utilize a converging entrance section to force subcritical entrance flow through critical. Unlike Parshall flumes, Cutthroat flume construction simplifies due to a flat horizontal floor and the absence of a throated section. Cutthroat flumes can be operated in non-submerged and submerged conditions. Yet, the flumes are most accurate when operated in non-submerged conditions. Due to the lack of a throat, the joining of the converging and diverging sections of the Cutthroat flume produces flow separation down-stream of the sharp joint. Thus, no theoretical analysis of the flow field has been developed and stage-discharge relationships are obtained by experimentation only. Similar to Parshall flumes, when operated under non-submerged conditions the stage-discharge relationship can be related directly to the water depth measured upstream of the of the control section provided flow separation does not occur at the place of measurement. Measurement of this water depth should be taken at one-third of the distance downstream of the flume inlet. Figure 2.2 presents the basic configuration and dimensions of the Cutthroat flume. Note the absence of the throat in comparison to the Parshall flume.



where: $B = W + 2L_1 / 3 = W + L_2 / 3$;
$L_a = 2L / 9$; and
$L_b = 5L / 9$.

Figure 2.2 – Dimensions of the Cutthroat Flume (Ruth 1997)

In Figure 2.2, the variable, B, is the width of both the inlet and outlet of the flume, W, is the throat width, and, L, is the length of the flume. The variable, L_a, is the length from the throat of the flume to the upstream depth, h_a, and variable, L_b, is the length from the throat of the flume to the downstream depth, h_b. Similar to the Parshall Flume, discharge through the Cutthroat flume under free-flow conditions can be determined from the following equation (Skogerboe and Hyatt, 1967):

$$Q = Ch_a^{n_1}$$ **Equation 2.3**

The free-flow coefficient, C, was defined by Bennett (1972) as:

$$C = KW^{1.025}$$ **Equation 2.4**

where: Q=Discharge, ft^3/s;
W=Flume width, ft;
H_a=Up-Stream flow depth, ft;
K=Flume length coefficient; and
n_1=Free flow exponent, which is the slope of the free flow rating curve when plotted on logarithmic paper.

Since implementation in the agricultural industry, vast experimental testing has been conducted upon Cutthroat flumes. Some of these investigations have included correction factors for uneven settlement of flumes, and scaling effects of Cutthroat flumes. An examination of the Cutthroat flume literature did not produce any studies related to the development of a rating equation for supercritical flow conditions.

2.3 REVIEW OF PERTINENT LITERATURE

In an effort to empirically determine calibration equations for the Parshall flume currently installed at Reese Creek, a literature review was conducted. Subsequent sections provide a review of the pertinent literature pertaining to the Reese Creek flumes.

2.3.1 CHAMBERLAIN (1957)

Initial design, laboratory testing and prototype testing of the Trapezoidal Venturi Flume were discussed in this report. Design criteria of the Trapezoidal Venturi Flume included the ability to measure discharges over a wide range, the ability to pass heavy sediment loads, and the ability to measure discharge with a supercritical approach flow. Trapezoidal Venturi Flumes were initially designed for use in steep, small ephemeral mountain streams with slopes from 3 to 8 percent and a discharge range from 1 to 300 cubic feet per second (cfs). Figure 2.8 presents an isometric view of Trapezoidal Venturi Flume and also presents the dimensions and capacities of various Trapezoidal Flumes as given by Kilpatrick and Schneider (1983). Testing flumes at a 1:7 Froude scale were placed in a trapezoidal testing channel with a slope of 5%. The side slopes of the testing channel had a slope of 15 degrees from the horizontal and the slope of the flume side walls were 30 degrees from the horizontal. An abrupt transition consisting of a vertical wall between the channel and the upstream end of the flume was to direct flow into the flume. Calibration data were obtained for three different roughness types. These roughness were; (1) no roughness-the roughness of the testing channel only, (2) roughness induced by placing 1 (in.) square pieces of 0.5 (in.) thick plywood nailed 3 feet upstream of the flume on the floor and side slopes of the testing channel on 4 (in) centers, and (3) roughness induced by mimicking the previous roughness conditions except the thickness of the plywood was increased to 0.75 (in.).

Preliminary testing demonstrated the Trapezoidal Venturi Flume to be a promising device for measuring flow within steep ephemeral streams exhibiting a wide range of discharges. Insufficient data were available to compute Froude numbers in the approach section regardless of the roughness coefficient. Conclusions of the effect of roughness upon measuring the flow were also made. As flow approached the supercritical regime, the roughness coefficient had an important effect as supercritical flow is controlled from upstream. Through Chamberlain's research, the practical use of the trapezoidal flume in measuring flow during supercritical regimes has been recognized, indicating that there has been success in developing equations for measuring discharge with flumes in supercritical flow.

2.3.2 ROBINSON (1959)

An examination between the initial model study presented by Chamberlain (1957), another model study, and field measurements were addressed in this paper. Based upon Chamberlain's original 1:7 Froude scale model of the Trapezoidal Venturi Flume, a 1:6 Froude scale model was built for another model study. The flume was placed on a 5% sloping testing channel. A 4 foot rectangular channel was utilized for the testing channel, as opposed to the trapezoidal testing channel utilized in Chamberlain's initial testing. Several different testing channel geometries were utilized in field installations. Testing channels used in field installations varied from a 4 foot rectangular channel to a channel which had side walls of 30 degrees to one which had side walls of 15 degrees. Various approach conditions were studied to determine the affect upon flume measurements. Abrupt transitions were used for the rectangular testing channel and 15 degrees side sloped testing channel. Four degrees of roughness were also utilized in testing. Roughness was induced in the same manner as in Chamberlain's testing, with various widths and plywood thickness secured to the floor and side slopes of the testing channels.

Velocity head rods and current meters were utilized in the collection of field data. Measurements were made in both the approach and throated section of the installed flumes. Discharges were determined by using average velocity data. Field measurements indicated that velocities for lower discharges (5 cfs and lower) measured in the approach section were in the supercritical range. A transition zone occurred over the range of 5cfs to approximately 8cfs, and velocities measured at flow rates above 8cfs were subcritical in the approach section. Supercritical flow was induced for every flow rate within the throated section of the flume. For a head-discharge rating curve, the depth of flow must be measured in the center of the throated section. The magnitude of the velocity in the approach section affected the relationship in the throated section. A provisional rating curve was developed for use in field flumes with relative success.

The existence of supercritical approach flow at low discharges and subcritical flow at high discharges within the approach section was determined to be due to the throat acting as a control at higher discharges causing backwater and subcritical conditions. It was also concluded that any discontinuity with the intake measurement pipes with the flume would effect the water in the distilling well and should be avoided. Suggestions for future studies included a smoother transition from testing channel to testing flume, better equipment to accurately measure head in the throated section, better equipment to measure field discharges for calibration purposes and larger flumes sizes.

2.3.3 KILPATRICK AND SCHNEIDER (1983)

Kilpatrick and Schneider classify flow measurement flumes operating with supercritical approach flow into three categories. These categories are designated as: (1) Supercritical flow, width reduction, steep slope, (2) Supercritical flow, width reduction, drop in bed elevation, and (3) Supercritical flow, steep slope. As discussed under category (1), once critical discharge has been reached due to the contacted throat, supercritical flow in the throat can only be accomplished by increasing the available specific energy within the throat itself. This is accomplished by placing the flume upon a steep slope. Thus, category (1) supercritical flow flumes utilize a contracted, steep sloped placement to produce supercritical flow. Category (2) supercritical flow flumes also utilize a contracted throat, but require a drop in the bed to produce the required specific energy to force supercritical flow rather than a steep slope. It should be noted that the slope upstream and downstream of the drop in bed are the same for a category (2) supercritical flume. As discussed under category (3), contraction and an increase in specific energy are not necessary for supercritical flow to occur. Simply increasing the slope over a controlled, broad crested section can increase specific energy enough for supercritical flow to occur. Figures 2.3, 2.4, and 2.5 present categories (1), (2) and (3).

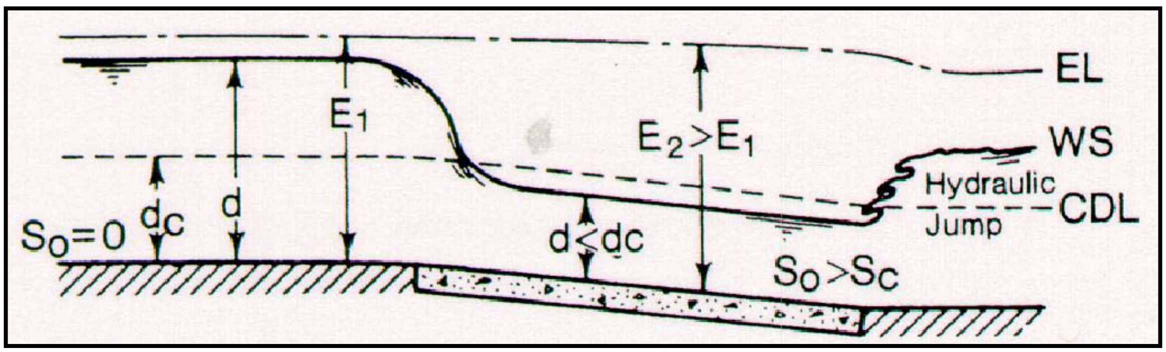


Figure 2.3 – Category (1): Supercritical Flow Contraction Obtained by Width Reduction and Sloping Bed (Kilpatrick and Schneider (1983)).

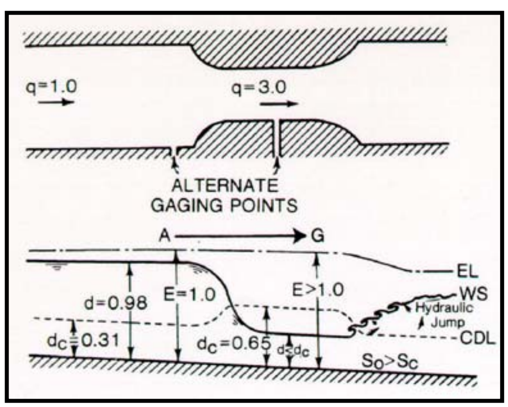


Figure 2.4 – Category (2): Supercritical Flow Contraction Obtained by Width Reduction and Drop in Bed (Kilpatrick and Schneider (1983)).

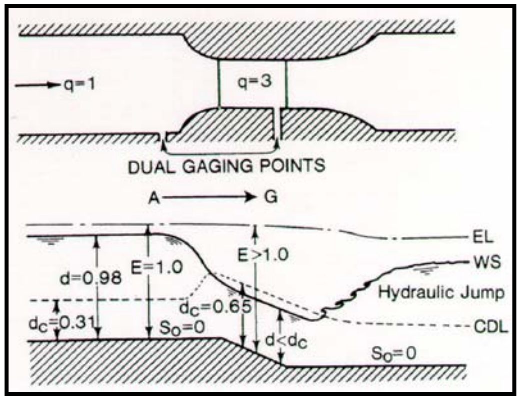


Figure 2.5 – Category (3): Supercritical Flow Obtained by Steep Slope (Kilpatrick and Schneider (1983))

where: E=Specific energy, ft;
d=Depth of flow, ft;
d_c=Critical flow depth, ft;
WS=Water surface;
EL=Energy line;
CDL=Critical depth line;
S_o=Bed slope, ft/ft; and
S_c=Critical slope, ft/ft.

Three different supercritical flow flumes were reviewed. These flumes were the San Dimas, Modified San Dimas and the Trapezoidal. The San Dimas Flume was developed for use in the San Dimas Experimental Forest to measure discharge of streams heavily laden with coarse debris. The flume consists of a converging approach, with a flat floor and a hump at the downstream end. A 3% sloped rectangular portion of the flume provides the specific energy required for supercritical flow. Due to this configuration, the San Dimas Flume falls into category (1) as previously defined. Head measurement occurs within the supercritical portion of the flume and related to a head-discharge relationship to determine discharge. For operation in low flows, the San Dimas Flume can be operated in conjunction with sharp-crested weirs that are bypassed during higher flows. Figure 2.6 presents the configuration and discharge ratings for different sizes of the San Dimas flume as originally designed.

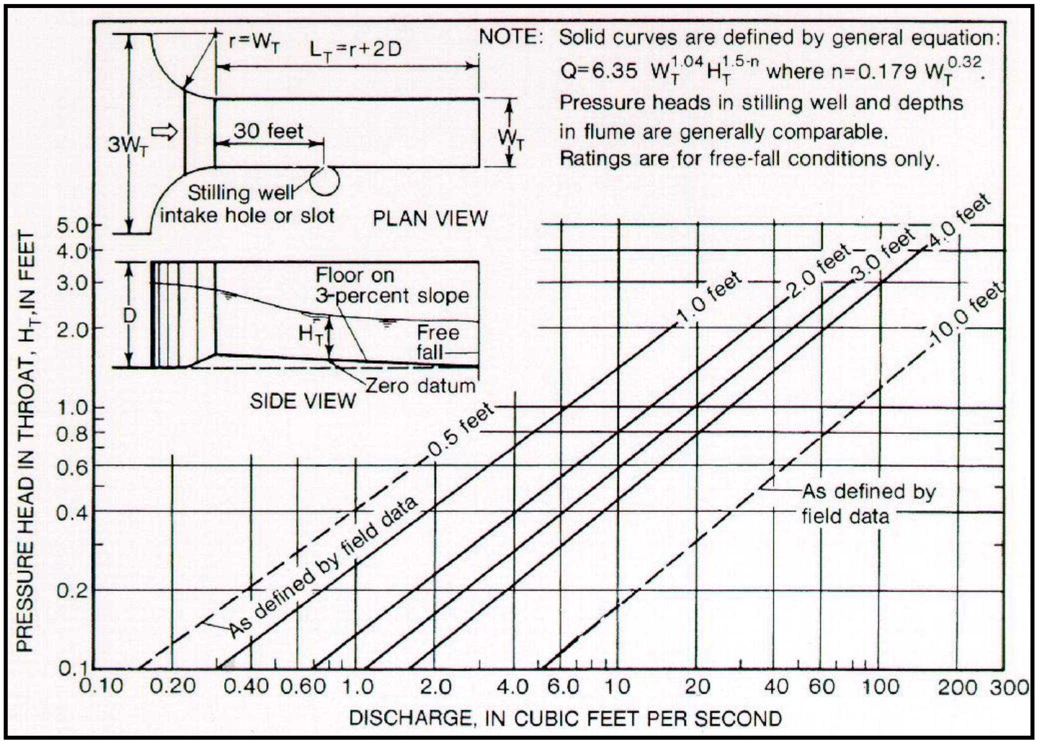


Figure 2.6 – Configuration and Discharge Ratings for Different Sizes of San Dimas Flumes as Originally Designed (Kilpatrick and Schneider (1983)).

In 1950, K.J. Bermel proposed modifications to the San Dimas Flume, which has been designated as the Modified San Dimas Flume. The major modifications include the narrowed approach relative to the width of the throat and the convergence of the side walls was made less abrupt. The hump at the downstream end was removed due to it being a potential sediment trap and having no effect upon the operation of the flume. The placement of head measurement was also moved from 30 feet downstream of the throat section to mid-length of the throat section. Figure 2.7 Presents the configuration and discharge ratings for different sizes of the modified San Dimas Flume.

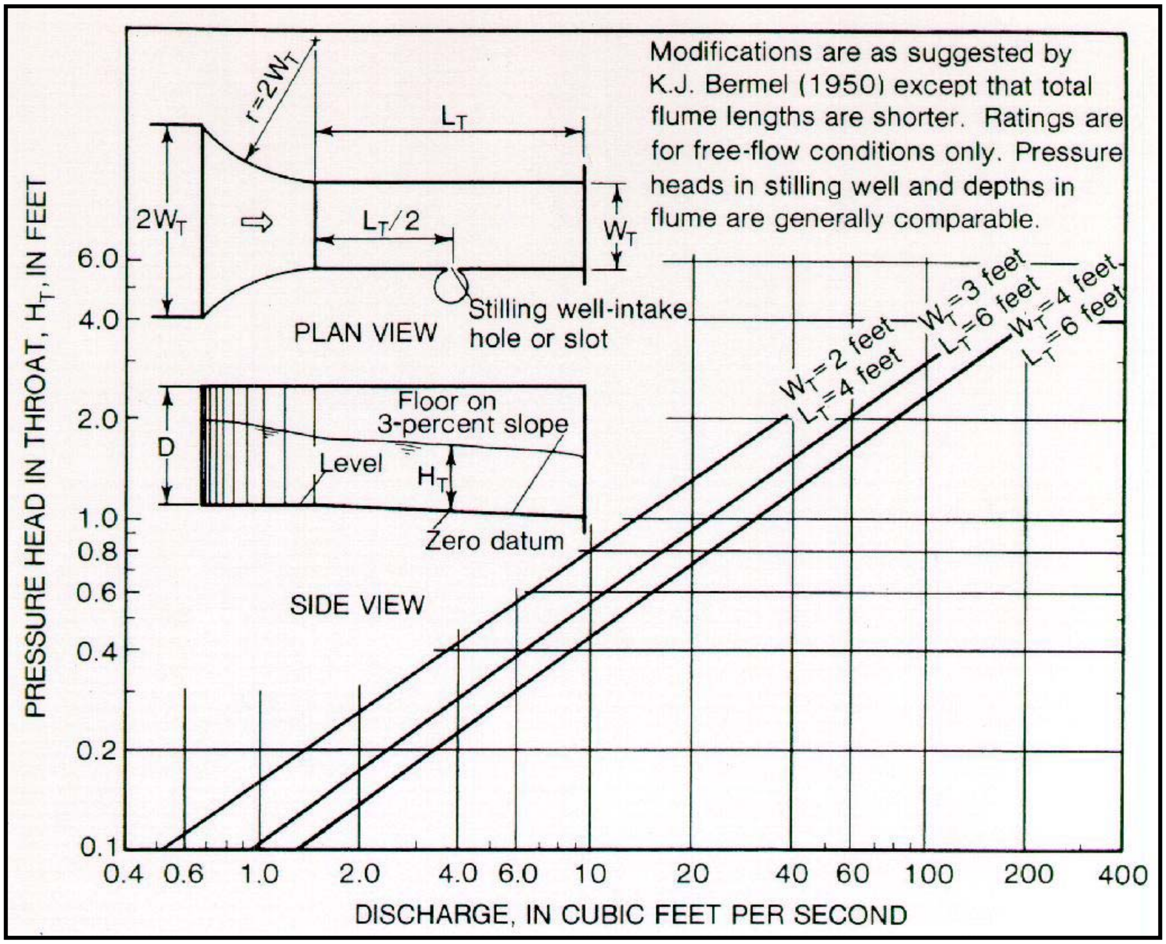
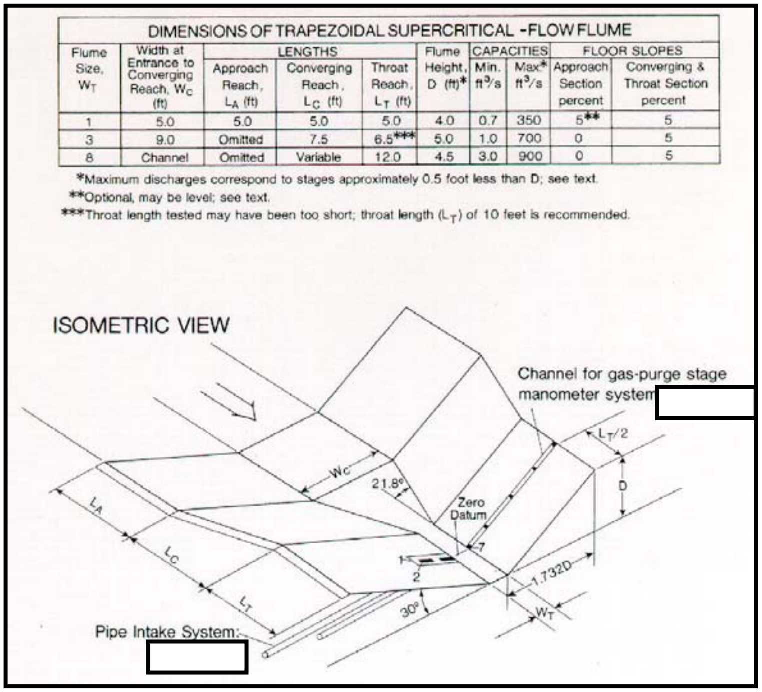


Figure 2.7 – Configuration and Discharge Ratings for Different Sizes of the Modified San Dimas Flume (Kilpatrick and Schneider (1983)).

In the late 1950's Chamberlain and Robinson designed a trapezoidal supercritical flow flume. Due to the vertical walls utilized by the San Dimas Flume, an insensitivity to head-discharge relationships at low flows occurs. To compensate for this effect, the trapezoidal flume was designed with sloping side walls so that the floor width would always be narrower than the top width at all cross sections. The trapezoidal flume uses a unique geometry to create backwater upstream into the approach reach. Without this unique geometry, critical flow would occur at the break in floor slope at the downstream end of the approach reach and supercritical flow would occur at every cross section downstream of the approach reach. Due to the sharp constricting width of the throat section, critical flow occurs downstream of this sharp constriction. Thus, flow is subcritical in the approach and converging reaches, while supercritical flow occurs within the throat reach. An isometric view of a trapezoidal channel can be seen in Figure 2.8.



DIMENSIONS OF TRAPEZOIDAL SUPERCRITICAL -FLOW FLUME									
Flume Size, W_T	Width at Entrance to Converging Reach, W_C (ft)	LENGTHS			Flume Height, D (ft)*	CAPACITIES		FLOOR SLOPES	
		Approach Reach, L_A (ft)	Converging Reach, L_C (ft)	Throat Reach, L_T (ft)		Min. ft^3/s	Max* ft^3/s	Approach Section percent	Converging & Throat Section percent
1	5.0	5.0	5.0	5.0	4.0	0.7	350	5**	5
3	9.0	Omitted	7.5	6.5***	5.0	1.0	700	0	5
8	Channel	Omitted	Variable	12.0	4.5	3.0	900	0	5

*Maximum discharges correspond to stages approximately 0.5 foot less than D; see text.
**Optional, may be level; see text.
***Throat length tested may have been too short; throat length (L_T) of 10 feet is recommended.

Figure 2.8 – Configuration, Dimensions, and Capacities for Trapezoidal Flume as Built by Chamberlain and Robinson (Kilpatrick and Schneider (1983)).

Similar to the Modified San Dimas Flume, head measurement occurs at the mid-length of supercritical throat and referred to a stage-discharge relationship to determine discharge. Preliminary discharge ratings for trapezoidal supercritical flow flumes can be computed utilizing the Bernoulli equation within the throat reach upstream from the head measurement site. Equating total energy at the critical depth cross section (c) at the head of the throat reach to total energy at the stage-measurement cross section (m), Bernoulli's equation yields (Kilpatrick and Schneider (1983)):

$$\frac{V^2{}_c}{2g} + d_c + Y_c = \frac{V^2{}_m}{2g} + d_m + Y_m + h_e$$

Equation 2.5

where: V=mean velocity, ft/s;
g=acceleration due to gravity, ft/s^2;
d=Vertical depth, ft;
Y=Elevation of flume floor above arbitrary datum, ft; and
h_e=friction loss between two sections, ft.

Due to the short length of reach the assumption that h_e may be considered negligible can be made. Substituting equation 1.5 into the two equations $Q=A_cV_c=A_mV_m$ and $\Delta Y=Y_c-Y_m$, equation 1.6 will be produced:

$$\frac{Q^2}{2gA_c{}^2} + d_c + \Delta Y = \frac{Q^2}{2gA_m{}^2} + d_m$$

Equation 2.6

where: A_m=Cross sectional area at section m, ft^2; and
A_c= Cross sectional area at section c, ft^2.

From Chow (1959), the critical section factor (z) is computed by the following equation along with discharge:

$$Z = A_c\sqrt{\frac{A_c}{T_c}}$$

Equation 2.7

$$Q = Z\sqrt{g}$$

Equation 2.8

where: T_c=Top width at the critical depth cross section, ft.

2.3.4 SMITH, ET AL. (1981)

The design and implementation of a supercritical flow flume called the Walnut Gulch flume was addressed. Currently installed in the Walnut Gulch reach near Tombstone, Arizona, the unique flume design was based upon both the San Dimas and trapezoidal supercritical flumes previously addressed. Due to the steep slope and ephemeral nature of the watershed, standard critical-depth flumes were found to be inadequate to accurately measure discharge and pass the large amounts of sediment-laden flow through the flume.

The design of the Walnut Gulch flume was a compromise between the properties of the San Dimas and trapezoidal flumes. The flume was constructed with a curved entrance approach and a long straight section having a v-shaped floor and side sloped walls at a 1H:1V slope. Model studies were performed upon the original design. A 1:32 Froude scale model was tested to determine the best placement to measure head within the supercritical throat. The midpoint of the narrow, straight portion of the flume was selected as the best point to measure head. A larger scale study of the original flume was conducted at Colorado State University's Engineering Research Center. The 1:5 scale was used to better define low flow ratings that were inaccurate at the 1:32 scale. These measurements were then evaluated with measurements taken from the prototype installed in Walnut Gulch.

Results from the prototype installation were in agreement with results obtained in the laboratory. The design and development of the supercritical flume addressed in this paper shows that supercritical flow flumes can be designed for specific reaches. Another conclusion of this paper was that exceptionally wide flumes built to fit the geometry of the channel will probably require the use of flow controlling devices upstream of the flume to reduce asymmetrical flow through the flume. Lastly, it was proven that the best placement of head measurement within the supercritical throat was at the midsection of the throat, as discussed previously.

2.4 SUMMARY

In conclusion, to the literature review performed, no specific solutions to the flow measurement difficulties observed at Reese Creek were determined. However, the literature review did reveal that supercritical measurement flumes have been developed in the past with some success. The complex nature of the supercritical flow regime complicates discharge measurement. Supercritical flows that carry large amounts of sediment cannot be forced into the subcritical regime for flow measurement with critical-depth flumes due to the excessive sedimentation that would occur upstream of the measurement flume.

Chamberlain (1957) and Robinson (1959) reported upon the effect of roughness in calibration of the Trapezoidal Venturi Flume. Various degrees of roughness were induced upon initial testing and calibration of the original Trapezoidal Venturi Flume. Roughness coefficients were found to have an affect upon the stage-discharge relationship during supercritical approach flows only. Concluding that supercritical approach flows are controlled by upstream conditions.

Kilpatrick and Schneider (1983) provided an analysis of how supercritical flow can be induced in measurement flumes. The design and implementation of the San Dimas and Modified San Dimas measurement flumes provided proof that supercritical flumes without the complicated geometry of a trapezoidal flume can be effective. Yet, these flumes are relatively insensitive to head-discharge relationships at low flows. As a result, trapezoidal flumes are more applicable for measuring discharges over a wide range.

Lastly, Smith et al (1981) showed that supercritical flow flumes could be designed and calibrated for particular flow situations. The Walnut Gultch supercritical flow flume was the solution to flow measurement difficulties experienced upon ephemeral streams in Arizona. It was concluded that the middle of the throated section was best placement of the head measurement device for supercritical flumes. Through hydraulic testing and field calibration, the Walnut Gultch Flume was proven to be the latest development of supercritical measurement flumes.

In conclusion, even though the literature review has not provided a specific solution to flow measuring difficulties experienced at Reese Creek, it has provided numerous examples of the successful development of supercritical measurement flumes. The supercritical approach flow currently entering the critical-depth flumes at Reese Creek provide inaccurate estimates of discharge when standard stage-discharge curves are utilized. The literature review did not reveal an existing rating equation for use on the Parshall flume installed at Reese Creek, therefore Phase 2 of this study is recommended. Based upon the completed literature review, it is hypothesized that empirical rating equations could be developed through hydraulic testing (Phase 2) and may present the only solution to the difficulties observed at Reese Creek. These rating equations will be dependent upon upstream roughness due to the supercritical approach flow, which will be of concern in the modeling process.

3 FIELD CHARACTERISTICS

Based on the findings from the literature review, a test program for Phase 2 will be developed to evaluate the feasibility of generating rating equations for Parshall and/or Cutthroat flumes installed in supercritical flow regimes. In addition to the findings from the literature review, the field characteristics of the flumes at Reese Creek are essential for the development of a test program for Phase 2. Subsequent paragraphs describe and discuss the field characteristics from Reese Creek.

Reese Creek is a high mountain, steep gradient stream tributary to the Yellowstone River. Average annual flow is estimated to be 10.4 cubic feet per second (cfs). Estimated mean monthly flows for the monitoring period, May through September, range from 6 to 40 cfs with peak flow typically occuring in June. Reese Creek structures consist of two Parshall flumes (upper and lower) and three diversion structures. The upper flume provides the monitoring point for flow entering the reach and the means to calculate allowable diversion flow rates. As all water users are authorized to take flow readings at the upper flume, Phase 2 will focus on an examination of the characteristics associated with the upper flume. The upper flume consists of a Parshall flume with a throat width of 5 feet. Flume construction consists of sheet metal with concrete wing walls. Figure 3.1 presents a photograph of the Upper flume.

Figure 3.1 – Photograph of the Upper Parshall Flume

From the available survey data for the Reese Creek flumes, channel bed slopes upstream of each flume were calculated. For the upper flume, the calculated slope was 4.95 percent and for the lower flume, the slope was calculated as 6.85 percent. From the available pebble count data for the material upstream of the upper flume, a grain size distribution (GSD) curve was generated. Table 3.1 presents the data utilized to generate the GSD. Figure 3.2 presents the grain size distribution for the bed material upstream of the upper Parshall flume. From Figure 3.2, the D_{50} was estimated at 254 mm (10 inches). From the D_{50} and the upper flume channel slope, a roughness in terms of Manning's n was determined to be approximately 0.041 (From Abt et al., 1988). This value of roughness is consistent with the range of roughness values reported by Van Haveren, 1986 for mountain streams with no vegetation in the channel, trees and brush along the banks with the channel bottom consisting of gravels, cobbles, and few boulders (range 0.030 to 0.050).

Utilizing the findings from the literature review and the field characteristics described above, a proposed test matrix was developed and is presented in Table 3.2. It is anticipated that Phase 2 will take approximately 2 months to complete.

Table 3.1 – GSD Data for Bed Material Upstream of Upper Parshall Flume

Grain Size (mm)	Accumulated Percent Retained	Percent Finer
2048	0.9	99.1%
1024	16.0	84.9%
512	35.9	66.2%
256	52.8	50.2%
128	66.0	37.7%
64	75.5	28.8%
32	77.4	27.0%
16	79.3	25.2%
8	79.3	25.2%
4	81.1	23.5%
2	81.1	23.5%
1	83.0	21.7%
0.5	84.0	20.8%
0.25	84.9	19.9%
0.125	92.5	12.8%
0.0625	93.4	11.9%
< 0.0625	100.0	5.7%
Total Count	106.0	0.0%

Table 3.2 – Proposed Test Matrix

Test Number (#)	Discharge (cfs)	Slope (%)	Roughness (n-value)
1	Flow 1	3	n-1
2	Flow 2	3	n-1
3	Flow 3	3	n-1
4	Flow 4	3	n-1
5	Flow 5	3	n-1
6	Flow 1	5	n-1
7	Flow 2	5	n-1
8	Flow 3	5	n-1
9	Flow 4	5	n-1
10	Flow 5	5	n-1
11	Flow 1	7	n-1
12	Flow 2	7	n-1
13	Flow 3	7	n-1
14	Flow 4	7	n-1
15	Flow 5	7	n-1
16	Flow 1	3	n-2
17	Flow 2	3	n-2
18	Flow 3	3	n-2
19	Flow 4	3	n-2
20	Flow 5	3	n-2
21	Flow 1	5	n-2
22	Flow 2	5	n-2
23	Flow 3	5	n-2
24	Flow 4	5	n-2
25	Flow 5	5	n-2
26	Flow 1	7	n-2
27	Flow 2	7	n-2
28	Flow 3	7	n-2
29	Flow 4	7	n-2
30	Flow 5	7	n-2
31	Flow 1	3	n-3
32	Flow 2	3	n-3
33	Flow 3	3	n-3
34	Flow 4	3	n-3
35	Flow 5	3	n-3
36	Flow 1	5	n-3
37	Flow 2	5	n-3
38	Flow 3	5	n-3
39	Flow 4	5	n-3
40	Flow 5	5	n-3
41	Flow 1	7	n-3
42	Flow 2	7	n-3
43	Flow 3	7	n-3
44	Flow 4	7	n-3
45	Flow 5	7	n-3

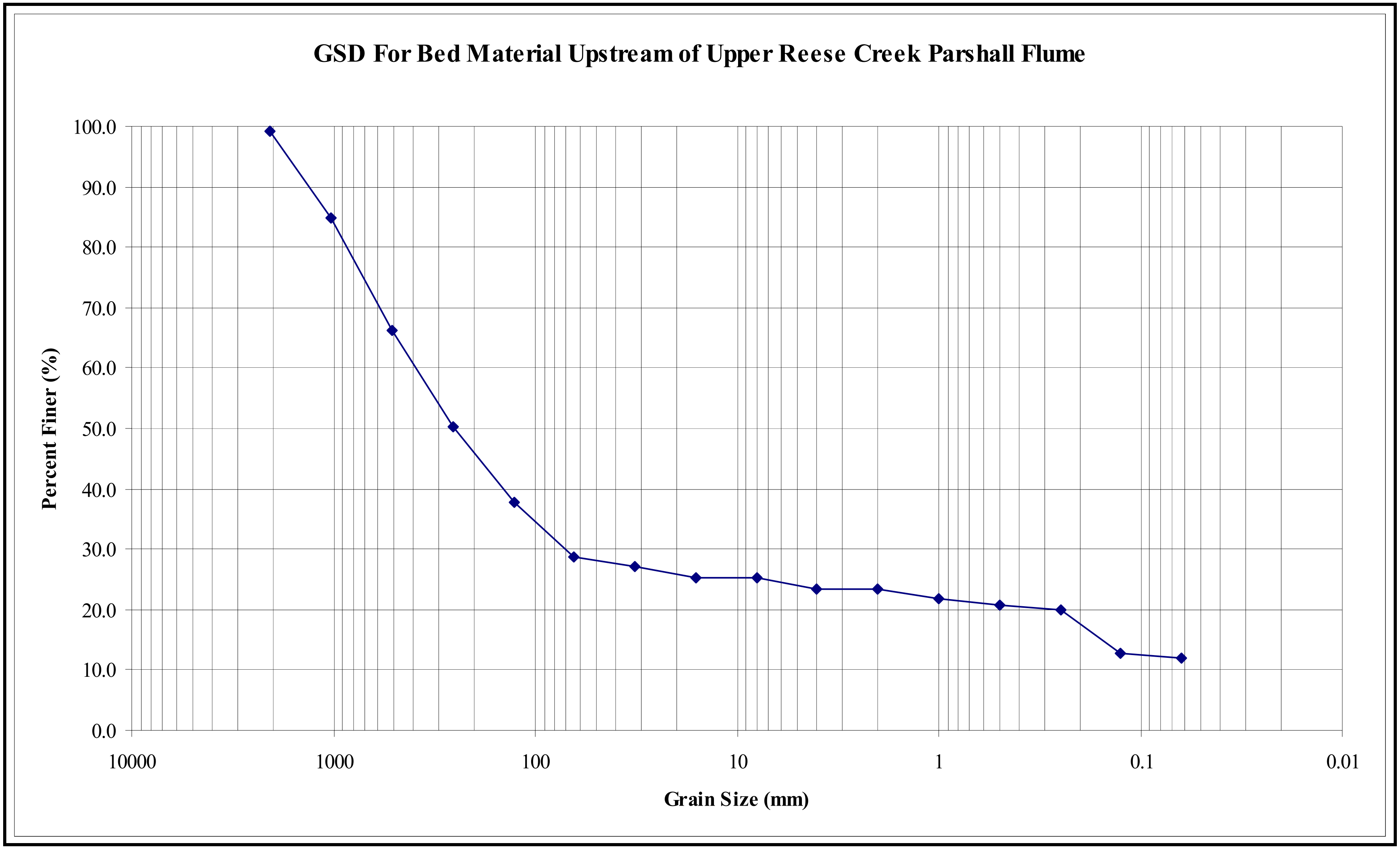


Figure 3.2 – Grain Size Distribution for the Bed Material Upstream of the Upper Parshall Flume

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